Fusion of SAR and TM Data for Quantitative Estimation of Forest Variables Over an Extended Range of Validity

Mahta Moghaddam[1] and Jennifer L. Dungan[2]

[1]Jet Propulsion Laboratory, MS 300-227, 4800 Oak Grove Drive, Pasadena, CA 91109 USA
Tel.: (+1) 818-354-1591, FAX: (+1) 818-393-5285, Email: mahta.moghaddam@jpl.nasa.gov

[2]CSUMB, NASA Ames Research Center, MS 242-4 Moffett Field, CA 94035-1000 USA
Tel.: (+1) 650-604-3618, FAX: (+1) 650-604-4680, Email: jdungan@mail.arc.nasa.gov

ABSTRACT

Near-simultaneous AIRSAR and Landsat TM data are used, along with radar scattering models and optical regression-based models, to estimate vegetation variables for a mixed old-growth dense forest in the US Pacific Northwest. The main variable of interest here is the foliage biomass, which is related to fundamental scattering properties of the forest stands used to model SAR data, through the allometric relations for the species under study. Polarimetric and interferometric SAR data and the Landsat TM data are first coregistered, taking care of the effects of surface topography. Relationships between foliage mass and TM data channels are derived through a regression analysis applied to ground measurements of the variable. Analytical scattering models are used to derive parallel relationships between SAR data and foliage mass. A nonlinear estimation algorithm applied simultaneously to both data types results in estimates of foliage mass which are expected to be more accurate and have a larger range of validity than what could be obtained from either data type alone.

1. INTRODUCTION

Fusion of optical and radar data to estimate forest variables has many potential advantages over using either data type alone. For estimating the same number of variables, it may increase the accuracy of estimates and it may allow the variables to be estimated over a larger range of validity. We have previously demonstrated these advantages through a regression-type analysis using field data of leaf biomass and near-simultaneous AIRSAR and Landsat TM data in the H.J. Andrews forest in Oregon [1] (see Figure 1). Here, we expand this work by replacing the regression analysis for radar data with a scattering model-based solution. The numerical scattering model is used to simulate all channels of radar data assuming the knowledge of forest variables over a "typical" range and to express the generated results as closed-form functions, such as polynomials, of a small number of independent variables. These functions are used in a nonlinear optimization algorithm, together with the regression model for TM data, to estimate the variables. Since the independent variables entering the radar scattering solution are different from those in the optical regression model, allometric relations of the species under study will be used to relate the two variable sets. Here the knowledge of species type will be assumed, and the variable set will be limited to one variable, foliage biomass. Results are compared with available field measurements for 25 reference plots. A thorough error analysis will be carried out to characterize the statistical accuracy of the estimation results with respect to errors in the microwave scattering and optical reflectance models. The foliage mass data are ultimately to be used to derive leaf area index (LAI), an essential driving variable for forest process models.

2. DATA CHARACTERISTICS

The remote sensing (RS) data to be used in this study are collected over the H. J. Andrews Forest in Oregon, one of the Long-Term Ecological Research (LTER) sites in the US. This area consists of various dense old-growth conifer stands, with biomass values ranging from less than 100 tons/hectare to over 1000 tons/hectare. The average altitude is about 950 m, with the lowest and highest points at about 600m and 1700m, respectively. There are several permanent GPS monuments and meteorological stations. The forest stand characteristics have also been extensively documented. In particular, foliage biomass and leaf-area index (LAI) values for approximately 30 reference stands have been reported [2]. These will be used to construct the TM regression models, as well as to validate the unified estimation algorithm results. The remote sensing data consist of polarimetric C-, L-, and P-band radar data from the JPL airborne SAR

(POLSAR/AIRSAR), the C-band single-polarization data from the JPL topographic SAR (TOPSAR), and the Thematic Mapper (TM) data from Landsat, all acquired in late April 1998. The range pixel spacing of the POLSAR is 3.3m for C- and L-bands and 6.6m for P-band. The TOPSAR pixel spacing is 10m, and the TM pixel size is 30m. Radiometric and polarimetric calibrations have been carried out on the POLSAR data. Due to pronounced topography, the radiometric calibration involves an added step to remove the effect of local slopes. The Landsat TM data were acquired under almost cloud-free conditions. All radar data are coregistered to the TM data, since the latter are already geocoded. Ground control points are chosen manually to tie the various datasets.

Of the 15 AIRSAR, 2 TOPSAR, and 6 TM principally independent data channels, only a subset is actually useful and practically independent. Examples are shown in Figure 2(a)-(d) of data correlations, where is some cases two or more data channels vary almost linearly with each other, and are hence not independent (Figure 2(b,c)). Other channels, as shown in Figure 2(a) and to some extent in Figure 2(d), do not exhibit such obvious linear dependence, and may hence be good candidates to be used in estimation. The final group of data channels to be used is still under investigation, but tentatively includes TM bands 1,2,4,7, TOPSAR C-VV correlation, TOPSAR topographic map, POLSAR L-HV, P-HH, and P-HV.

3. SCATTERING AND REFLECTANCE MODELS

The relationships between foliage mass and TM reflectance data were established through a polynomial regression analysis. The correspondence between RS data and the ground data points was made by using ENVI, where the ground plots were superimposed on the RS data as a vector layer. For each location, a 5 by 5 box was used to calculate the average reflectance value.

The relationships between foliage mass and various channels of the AIRSAR data were derived by simulating them using a numerical forest scattering model [3] and inputting typical ranges of canopy variables. Allometric relations were used to relate foliage mass to scattering properties such as expected tree heights, branch densities, and diameters. The AIRSAR simulation results were fitted to polynomials with foliage mass as the independent variable.

4. VARIABLE ESTIMATION

Once both SAR and TM data are expressed as closed-form functions, in this case polynomials, of the independent variable foliage mass, they can be used simultaneously in an estimation algorithm. Here, we have used a nonlinear optimization technique with an iterative conjugate gradient algorithm at its core. Solutions are found within a few (10-20) iterations given a tolerable error condition. Statistical accuracy of the estimates are studied by superimposing polynomial coefficient noise with uniformly Gaussian distribution, repeating the estimation many times, and averaging the results.

5. RESULTS

The above algorithm is applied to the radar and optical data to estimate foliage biomass within the H.J. Andrews forest. The results are compared to those generated previously where SAR data were also related to foliage biomass through regression models. It will be shown that the analytical scattering models produce more accurate estimation results that can be applied to a wider range of stands provided that accurate allometric relations are available. Numerical results will be shown at the presentation.

REFERENCES

[1] Moghaddam, M., J. Dungan, and J. Coughlan, "Fusion of SAR and TM data for parameter estimation and classification in dense and hilly forests," *Proc. IGARSS*, Hamburg, Germany, 1999.

[2] Means, J., et al., "Use of large-footprint scanning airborne lidar to estimate forest stand characteristics in the western Cascades of Oregon," *Remote Sens. Environ.*, vol. 67, pp. 298-308, 1999.

[3] Moghaddam, M., and S. Saatchi, " Monitoring tree moisture using an estimation algorithm applied to SAR data from BOREAS," *IEEE Trans. Geosci. Remote Sensing*, vol. 37, no. 2, pp. 901-916, 1999.

ACKNOWLEDGMENT

This work was performed in part by the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, and in part by the NASA Ames Research Center, Moffett Field, CA, both under contract from the National Aeronautics and Space Administration.

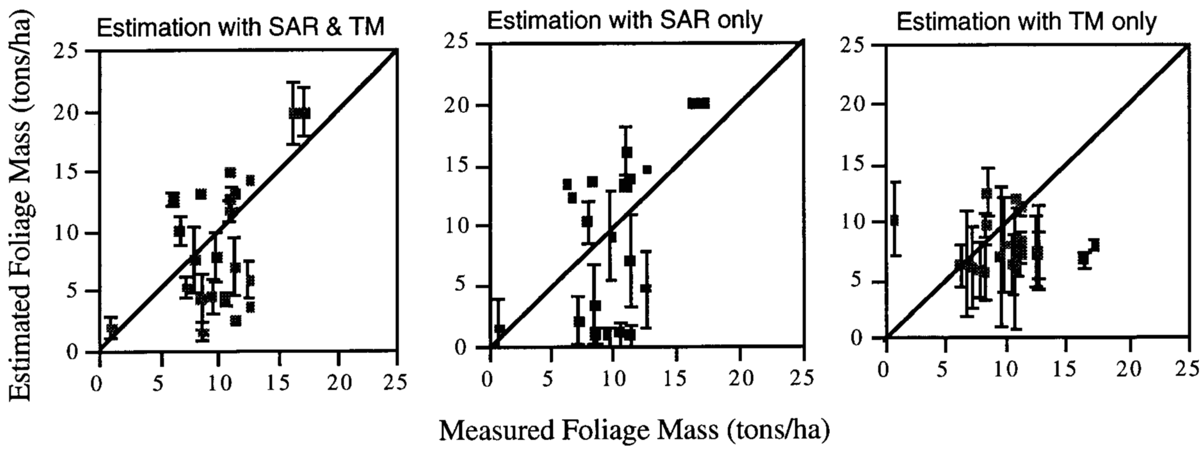

Figure 1. Estimation accuracy is best when both SAR and TM data are used together.

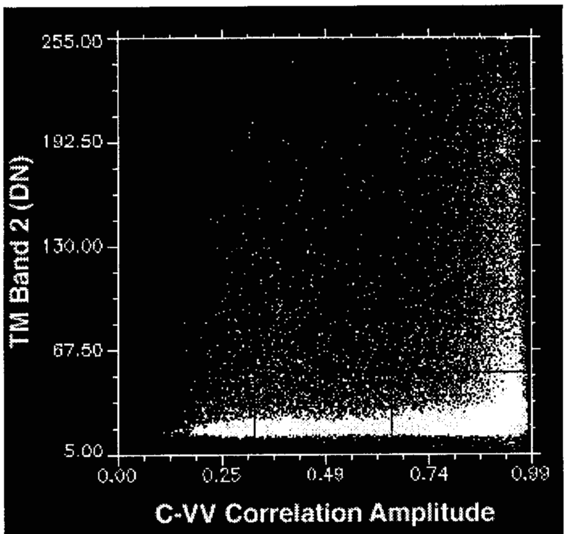

Figure 2(a). Scatter plot of TM-2 and C-VV Correlation

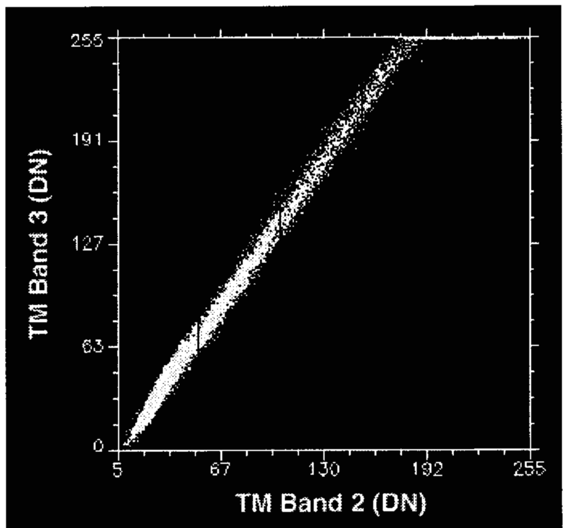

Figure 2(b). Scatter plot of TM-3 and TM-2

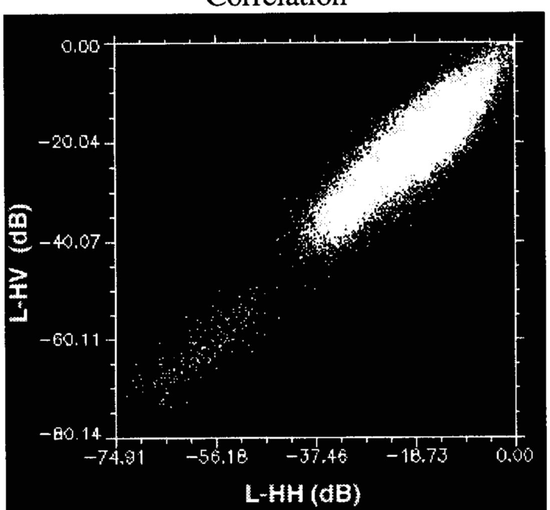

Figure 2(c). Scatter plot of L-HV and L-HH

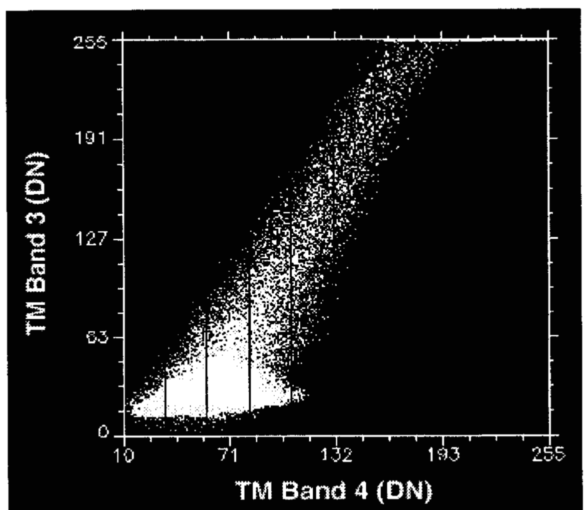

Figure 2(d). Scatter plot of TM-3 and TM-4